Recent Results in Hadron Spectroscopy from CLEO and the CLEO-C Project

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Abstract: We present three new results in hadron spectroscopy obtained by the CLEO Collaboration. These are the first measurement of the D^{*+} width, a new measurement of the $\gamma\gamma$ partial widths of χ_{c0} and χ_{c2}, and the results of a search for the radiative decay $\Upsilon(1S)\to\gamma\eta'$. In addition, we present plans of the CLEO Collaboration to take very high statistics e^+e^- data in the $\sqrt{s} = 3-5$ GeV region, opening the door to precision QCD studies.

On June 26, 2001, the CLEO experiment took its last data at the $\Upsilon(4S)$. While the study of B physics has been the chief experimental contribution by CLEO in the past two decades, the collaboration has also studied many other subjects, which include two photon production of C-even mesons, charm meson production and decay, etc. In this paper we present three results of such studies, and discuss a possible future project at CESR, whose physics emphasis is charm physics and QCD.

1. CLEO Hadron Spectroscopy Results

All of the data used in the analyses presented in this talk were obtained using CLEO II or II.V detector configurations, which have been described in detail elsewhere [1, 2]. The data were taken in symmetric e^+e^- collisions at energies near $\sqrt{s} = 10$ GeV, provided by the Cornell Electron-positron Storage Ring (CESR).

1.1 Mass and Width of D^{*+}

A measurement of $\Gamma(D^{*+})$ gives some unique information about the non-perturbative strong dynamics of heavy quarks. Since the level splitting in the B sector is not large enough to allow real strong transitions, this information can come only from $D{*}{+}$ decays. Predictions for the width vary widely, from 15 keV to 150 keV [3], and experimetnally, the

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only result to date is a 90%CL upper limit of 131 keV.[4] The present result is based on the full CLEO II.V data set (9.0 fb^{-1} of e^+e^- collisions at or near $\Upsilon(4S)$) and involved full reconstruction of the D^{*+} in a single decay chain, $D^{*+} \to \pi^+_{\rm slow} D^0$, $D^0 \to K^-\pi^+$.

The challenge of measuring the width of D^{*+} is understanding the tracking system response function since the experimental resolution exceeds the D^{*+} width. Therefore exhaustive comparisons between a GEANT [5] based detector simulation and our data are required in order to obtain $\Gamma(D^{*+})$. These studies and the analysis are described in detail in [6].

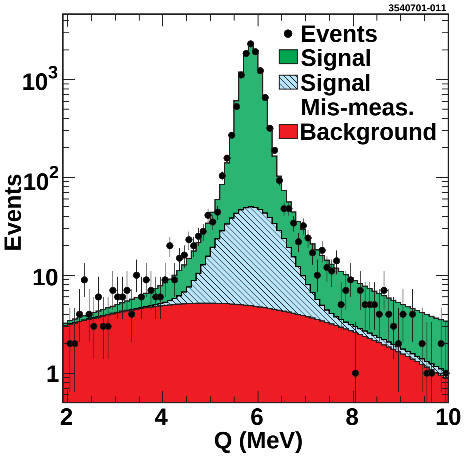

Figure 1: Fit to the Q distribution for $D^{*+} \to \pi^+_{\rm slow} D^0$.

Our reconstruction method takes advantage of the small CESR interaction region and the kinematics and topology of the $D^{*+} \to \pi^+_{\rm slow} D^0 \to \pi^+_{\rm slow} K^-\pi^+$ decay chain. The flat ($\sigma_{vertical} \sim 10\ \mu$m) interaction region allows us to re-fit the slow π^+ track, constraining it to intersect this vertex region. The resulting improvement of 30% in the energy release (Q) resolution is crucial to this measurement. σ_Q is typically 150 keV, and is very well modeled by the detector simulation.

Assuming $\Gamma(D^0)$ to be negligible, the Q distribution is simply a convolution of a P-wave Breit Wigner function for the D^{*+} and the tracking system response function obtained event by event by propagating tracking errors. The D^{*+} width is then obtained through an unbinned maximum likelihood fit to the Q distribution (See Fig.1). From this fit we obtain $\Gamma(D^{*+}) = 96 \pm 4(stat) \pm 22(syst)$ keV. Further, the mean energy release obtained in the fit yields a mass difference $m_{D^{*+}} - m_{D^0} = 145.412 \pm 0.002 \pm 0.012$ MeV, which is in agreement with the PDG average of 145.436 ± 0.016 MeV. [7]

1.2 Two Photon Widths of χ_{c0} and χ_{c2}

The charmonium system is an ideal testing ground for QCD. CLEO has studied the two-photon production of the C-even 1^3P charmonium states χ_{c0} and χ_{c2} using 12.7 fb^{-1} of data from the CLEO II and II.V data sets. At CESR, C-even $c\bar{c}$ states are produced via the fusion of two space-like photons, radiated by the 5.3 GeV e^+ and e^- beams. In order to obtain the two photon partial width $\Gamma_{\gamma\gamma}$, we have measured the $\gamma\gamma$ cross-section for the χ_c states, which are detected via the $\pi^+\pi^-\pi^+\pi^-$ decay mode.

The invariant mass distribution of the selected events is shown in Figure 2. The data were fitted with a power law function background plus: for χ_{c0}, a Breit-Wigner function with $\Gamma = 14.9$ MeV[7] convolved with a double Gaussian function for detector resolution; for χ_{c2}, only the double Gaussian function was used, since its width of 2.0 MeV[7] is negligible compared to our mass resolution of ~ 9 MeV.

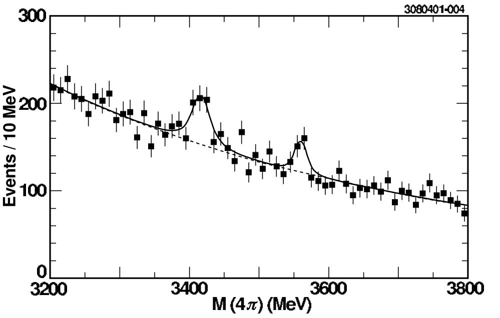

Figure 2: The $\pi^+\pi^-\pi^+\pi^-$ invariant mass (data point with errors). The solid line is the result of the maximum likelihood fit.

From the fit, we obtain 234 ± 40 candidate χ_{c0} events and 89 ± 25 candidate χ_{c2} events. Due to the large uncertainties in the hadronic branching fractions, we have chosen to express our primary results as the following products: $\Gamma_{\gamma\gamma}(\chi_{c0})\times\mathcal{B}(\chi_{c0}\to\pi^+\pi^-\pi^+\pi^-) = 75\pm13(\mathrm{stat})\pm 8(\mathrm{syst})$ eV and $\Gamma_{\gamma\gamma}(\chi_{c2})\times\mathcal{B}(\chi_{c2}\to\pi^+\pi^-\pi^+\pi^-) = 6.4\pm1.8(\mathrm{stat})\pm0.8(\mathrm{syst})$ eV. From this we obtain the ratio $\Gamma_{\gamma\gamma}(\chi_{c0})/\Gamma_{\gamma\gamma}(\chi_{c2}) = 7.4\pm2.4(\mathrm{stat})\pm 0.5(\mathrm{syst})\pm0.9(\mathrm{br})$, where the last uncertainty corresponds to branching fraction uncertainties that do not cancel in the ratio. Using the known 4π branching fractions, we obtain $\Gamma_{\gamma\gamma}(\chi_{c0}) = 3.76\pm0.65(\mathrm{stat})\pm0.41(\mathrm{syst})\pm1.69(\mathrm{br})$ keV and $\Gamma_{\gamma\gamma}(\chi_{c2}) = 0.53\pm0.15(\mathrm{stat})\pm0.06(\mathrm{syst})\pm0.22(\mathrm{br})$ keV, where the last uncertainties correspond to the systematic uncertainties arising from the hadronic branching fractions. The χ_0 measurement is the first published result for $\Gamma_{\gamma\gamma}(\chi_{c0})$,[8] significantly improving upon the unpublished Ph.D. thesis result of 4.0 ± 2.8 keV.[9] Our result for $\Gamma_{\gamma\gamma}(\chi_{c2})$ is consistent with and more precise than the current PDG average of 0.47 ± 0.17 keV.

We may obtain PQCD predictions using formulae presented in References [10] and [11]. For a range of $\alpha_s = 0.28-0.35$, we obtain predictions of $\Gamma_{\gamma\gamma}(\chi_{c0}) = 2.9-5.0$ keV and $\Gamma_{\gamma\gamma}(\chi_{c2}) = 0.25-0.47$ keV, both consistent with our results. The ratio $\Gamma_{\gamma\gamma}(\chi_{c0})/\Gamma_{\gamma\gamma}(\chi_{c2})$, which is more robustly predicted in pQCD, is $7-9$, also consistent with our result. More precise measurements of the branching fractions for this and other hadronic charmonium decays are necessary to constrain the pQCD predictions.

1.3 Search for the Radiative Decay $\Upsilon(1S)\to\gamma\eta'$

J/ψ radiative decays have revealed several "glue rich" states which are of interest, [7] and it is expected that radiative decays of $\Upsilon(1S)$ should produce the same states. Only one such decay ($\Upsilon(1S)\to\gamma f_2(1270)$) has thus far been published.[12] Here we report the results of another search, for $\gamma\eta'$. For this search, we used 61.3 pb^{-1} of data taken with the CLEO II detector[1] at the peak of the Υ(1S) (corresponding to approximately 1.45×10^6 Υ(1S) mesons).

Our search for $\Upsilon(1S)\to\gamma\eta'$ required full event reconstruction, involving the decay $\eta'\to\pi^+\pi^-\eta$, followed by $\eta\to\gamma\gamma$, $\eta\to\pi^0\pi^0\pi^0$, or $\eta\to\pi^+\pi^-\pi^0$. The analysis revealed no candidates, and thus we quote only a 90%CL upper limit of $\mathcal{B}(\Upsilon(1S)\to\gamma\eta') < 1.6\times10^{-5}$. Our result is a significant improvement over the Crystal Ball limit[13] of 1.3×10^{-3}. It also contradicts the models of Körner, which predict a rate of $5-10\times10^{-5}$[14]. Models by Intemann[15] and Ma[16] predict rates which lie below our present sensitivity. This result is rather small in comparison to radiative decays of other heavy vector mesons, and indicates the need for significantly more data at $\Upsilon(1S)$.

2. The CLEO-C Project

The CLEO Collaboration, CESR, and the Cornell University Laboratory of Nuclear Studies have planned an ambitious program of physics studies using CESR and the CLEO III detector in operation in the $\sqrt{s} = 3 - 5$ GeV energy range. We expect that this program of physics, ranging from precision measurements of charm meson branching fractions and form factors, to studies of J/ψ radiative decay, will substantially advance our understanding of important components of the Standard Model. Of particular interest to this parallel session are the studies of QCD physics via J/ψ radiative decay, and the associated program of Υ resonance physics that will begin in the late fall of 2001. These aspects of the CLEO-C program will be emphasized in these proceedings. The extensive program of charm meson and QCD studies, as well as the necessary CESR upgrades and the CLEO III detector are described in full in an LNS publication. [17]

The strong interaction sector of the Standard Model, particularly in its non-perturbative regime, is by most accounts far less well understood than the electroweak sector. The experimental data with which non-perturbative QCD may best be probed suffers in general from small statistics. Theoretically speaking, Lattice Gauge Theory has come to a point where, in the near term future, it will need far more experimental data to guide its development. The measurement by CLEO-C of $\Upsilon(nS)$ leptonic widths, radiative decays, and $b\bar{b}$ and $c\bar{c}$ spectroscopy will have far reaching effects for the Lattice Gauge community. The data expected from CLEO-C ought to help greatly in refining techniques for calculation not only in these limited regimes but also in calculation of B decay constants and form factors. These fact provides additional impetus for such studies as are proposed in CLEO-C.

The studies of radiative J/ψ decays by Mark III and more recently by the BES collaboration have hinted at very interesting physics - possibly the presence of QCD exotics. However, the total number of J/ψ decays recorded is only of the order of 50 million. The understanding of rare radiative decays to such interesting “glue rich” states is left, in many cases, to an analysis of handfuls of events, with enormous backgrounds. Partial Wave analyses have been helpful in disentangling the signals from the background for such decays, but results are largely inconclusive. The understanding of exotica such as glueballs and hybrids is, in the opinion of many in the hadronic physics community, an important input in the broader understanding of QCD and other strongly-coupled theories.

We address these physics in part by including in the CLEO-C run plan a program of 1-2 fb^{-1} of e^+e^- collisions on the peak of the J/ψ. This implies something of the order of 1 Billion J/ψ decays, or a factor of 20 higher statistics. In addition to the impressive gain in statistics, the CLEO-III detector’s superior solid angle coverage (93% for tracking and calorimetry, vs. 70% for BES) and energy and momentum resolution will increase the impact of these higher statistics. [17] This will make possible the discovery of many new radiative decays, and, we expect, the clarification of much of the radiative decay spectrum that is, today, quite murky.

Beginning in the fall of 2001, the CLEO Collaboration intends to spend several months accumulating data from e^+e^- collisions at the peaks of the three lower Υ resonances. For these $\Upsilon(nS)$ states only very small data sets exist. Many of the gross features of the $b\bar{b}$

spectrum have been observed, but there is much left to be desired: e.g., neither the singlet P states h_b, nor any singlet S state η_b, η'_b, have been observed. In addition, there are no hadronic decays of any $b\bar{b}$ state are known, and, as mentioned above, only one measurement of a radiative decay of $\Upsilon(1S)$ has been reported. Comparison of such decays to those in the $c\bar{c}$ system would be a boon to our understanding of the strong interaction. Observation of the singlet $b\bar{b}$ states would be a key piece in the puzzle of our understanding of the confining potential for heavy quark mesons.

CLEO-C offers a tantalizingly rich program of QCD and flavor physics whose reach will be unparalleled. Statistics will be increased by one or two orders of magnitude in J/ψ physics, $b\bar{b}$ spectroscopy, D and D_s production and decay, etc. As was stated in Ref. [17], "one order of magnitude opens new vistas; two orders of magnitude can change a field." CLEO-C, quite possibly, represents a revolutionary experiment in the field of hadron spectroscopy.

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